GEOTECHNICAL STUDY AREA G15

ROBIN HOOD'S BAY, NORTH YORKSHIRE, UK

Plate G15 ***Aerial view of Robin's Hood Bay, North Yorkshire, UK***

1. INTRODUCTION

1.1 Background

Robin Hoods Bay is situated on the north-east coast of England (Figure G15.1). The village is an important tourist attraction because of its unspoilt nature, ancient charm and the outstanding beauty of the surrounding countryside and coastline. It is situated within the North York Moors National Park and forms part of the North Yorkshire and Cleveland Heritage Coast (Plate G15).

The community was originally a fishing village, which, at its peak in the early 19th Century, was a more important fishing centre than the nearby town of Whitby. However, by the end of the 19th Century, the lack of harbour facilities prevented Robin Hood's Bay from remaining a viable port and the industry declined. The arrival of the railways in 1885 led to the expansion of the village and the development of the Mount Pleasant area, where there are large brick houses and hotels with southerly views across the Bay. Despite the closure of the railway in 1965 the village has continued to thrive, attracting tourists and retired people as well as providing homes for others who work in the surrounding area.

Robin Hood's Bay has had a long history of coastal erosion problems. Since a large landslide in 1780 which destroyed much of the original road into the village (Kings Street), over 200 cottages have been lost by cliff recession. Vertical concrete sea walls, 20 metres high and anchored to the cliff were built in 1975 to prevent erosion along "The Landing" a section of cliff located between the village slipway and Ground Wyke Hole. However, to the north of these walls, the coastline has remained exposed to wave attack. This has led to the development of a continuous cycle of marine and seepage erosion coupled with landsliding of the glacial till slopes which form the upper part of the coastal cliffs. These processes have led to intermittent cliff top recession and the loss of property, services and infrastructure, most notable in the 1930s and 1950s. At present the rear cliff top is visibly encroaching into the Victoria Hotel gardens (Plate G15a) and is extremely close to the road which provides the only road access into the village and also includes all the services.

The problems associated with cliff instability at Robin Hood's Bay are:

i) Much of the area lies within a large-scale multiple rotational landslide system. Large scale movement could occur on those slopes which would pose a considerable risk to structures and buildings. It was considered that there was a high probability of such movements occurring in the next 5 years.

ii) A section of the slopes below The Esplanade are supported by a sheet pile wall which is at risk of failure. The probability of failure occurring within the next 5 years was considered high.

A number of coastal studies have been commissioned by the Local Authority, Scarborough Borough Council, in order to review and evaluate the problems between Mount Pleasant and The Esplanade in order to:

(a) Ascertain the impact of coastal erosion processes on the problems currently being experienced at Robin Hood's Bay.

(b) Identify a preferred design solution.

(c) Provide enough information to permit the design of stabilization and coast protection works to be undertaken.

(d) Prepare a report to MAFF on the feasibility and options for coast protection and cliff stabilization works in support of a grant application.

(e) Undertake detailed coast protection and landslide stabilization design which has been followed by construction.

2. SITE DESCRIPTION

2.1 Topography and Study Area Description

The bay is approximately 400m in length and is bounded by Bay Ness Point to the north and South Cheek to the south (Figure G15.2). The site study area lies between Mount Pleasant and Ground Wyke Hole and features an eroding cliffline with a combination of overlying ancient landslides (which probably evolved over the last 10,000 years following the last Devensian glaciation), and much more recent landslide units. The study area is an extremely popular tourist attraction and is bounded by the old village and the more recent Victorian development of Mount Pleasant.

The ground profile across the site varies from near sea-level at the foot of the coastal cliffs to approximately 52m AOD adjacent to the Victoria Hotel. Within the study area the site can be broken down into a general composite profile that consists of 4 main elements.

1. A broad, gently sloping foreshore rock platform which extends several hundred metres beyond the low water mark. This platform is partly covered by a thin sandy beach at high watermark which tends to disappear then reappear depending on the prevailing sea state.
2. A 17-22 metre high near vertical sea-cliff developed in a rock sequence of shales (Lower Lias) capped by 12m-16m of glacial till. In the northern section of the area, the till cover gradually disappears to be replaced by the more competent sandy series of the Middle Lias.
3. A series of gently sloping narrow, elongate, mid-slope benches separated by short steep scarp slopes.
4. A 10-20 metre high, steep (up to 3°) rear cliff that rises from 32m AOD at the Esplanade to 52m AOD at the Victoria Hotel.

The relative significance of each of these elements varies across the site and gives rise to a complex cliff line of contrasting appearance.

2.2 Geology

The majority of the rocks forming the North Yorkshire moors are sedimentary and were deposited in the seas and river deltas (The Cleveland Basin) that covered the area during the Jurassic Period. Deposition of these sediments began approximately 213 million years ago and continued for another 62 million years. With the exception of the Cleveland Dyke (Tertiary) the youngest rocks in the region are 150 million years old. At the end of the Jurassic Period, uplift faulting and erosion took place forming the Cleveland Anticline.

Within the region there are many different types of Jurassic rock which can be conveniently divided into four groups, in descending order of occurrence.

- Kimmeridge Clay Group
- Middle Oolite Group
- Ravenscar Group (Deltaic Series)
- Lias Group

The Jurassic sediments within the site area predominantly belong to the Lias Group and have been subsequently uplifted to form a geological dome structure that was originally centred on the Bay. The dome has gradually been down cut by marine erosion forming the foreshore rock platform which extends approximately 30 metres seaward, at gradients of between 1 in 75 and 1 in 100.

The oldest deposits visible in the bay are the Siliceous Shales of the Lower Lias. These are overlain by Pyritious and Ironstone Shales which are exposed on the foreshore rock platform and in the sea cliffs of the study area. Overlying the shales is the Middle Liassic strata (sandy series) which is visible in the cliffs to the north and south of the study area. Over much of the bay, the solid geological sequence has been interrupted and everything from the base of the Middle Lias and in places, the upper parts of the Lower Lias have been removed by erosion. The erosional surface has subsequently become mantled in a thick covering of Glacial Till of Devensian Age, with the exception of the northern section of the site area where much of the Middle Liassic Strata has remained intact. This change in geology is reflected by a rugged cliff topography which becomes steeper and less prone to instability.

The glacial deposits on the site vary considerably in thickness and composition. These deposits can be broadly categorised into an upper (sandy) and lower (laminated silty till separated by irregular and variable deposits of sands, gravels and silts.

The general geology of the Robin Hood Bay study area is shown in Figure G15.3.

2.3 Groundwater

A ground investigation conducted in December 1996 confirmed that a series of perched water tables at sub-artesian pressures exist within the glacial deposits, particularly in the central and northern sections of the site area. This is consistent with observations made in similar investigations at Whitby (Clark and Guest 1991) and at Holbeck Gardens, Scarborough (Rendel Geotechnics 1995). The perched watertables are probably recharged by a line of springs believed to exist in the area of cliff top land located between the Victoria Hotel and Mount Pleasant. Some of these springs appear to have been diverted by land drains, the pipework of which emerges in the rear cliff, approximately 80m north of the Victoria Hotel. Water from this system probably emerges in the mid-slope bench, raising the water table to approximately ground levels in the area below the Victoria Hotel.

Groundwater is also probably entering the site via a deep sand/silt layer discovered in the rear cliff adjacent to the Victoria Hotel. Rotational failures at the toe of the mid-slope bench have probably disrupted the hydraulic continuity of this layer, trapping groundwater within the main body of the landslide. This water may be exerting large pore pressures on the base and sides of the landslides failure surface, resulting in further movement. Evidence of high pore pressures is provided by springs which discharge freely from an exposed gravel horizon in the sea cliff, during periods of heavy rainfall.

Groundwater was not encountered in any of the boreholes that were extended into the Lower Lias bedrock. Falling head permeability tests carried out as part of the site investigation indicated that the mudrocks are relatively impermeable ($2\text{-}5 \times 10^{-8}$ m/s) and hence provide little potential for under-drainage of the glacial till.

2.4 History of Marine Erosion and Landsliding

Comparison of the sea cliff position from old photographs and post editions of Ordnance Survey maps (1895 and the present day) indicate that sections of the site area are subject to significant rates of marine erosion. The highest rates of erosion have occurred in the north of the bay adjacent to the Victoria Hotel where some 22m of coastline has been lost during a 78 year period at an average rate of 0.29m/year. Regression of the rear cliff has also been concentrated in this area, resulting in the loss of some 50m of land from Victoria Hotel gardens and the diversion of the main road into the village.

To the south of the site area coastal erosion (0.15m./year) has exceeded regression of the rear cliff, increasing the slope angle and the potential for a large first time failure as the slopes are becoming progressively over steep. This is not without historical precedent as indicated by the events of 1780 in which a major failure destroyed the upper section of Kings Street (which had run from village slipway to what is now the cliff top car park) and two rows of cottages (Dalton 1914, Farnhill 1966 and Labistour 1996).

Historic records also indicate that since 1790 almost 200 cottages have been lost to marine erosion. Despite an agreement in 1956 between the then North Ridings County Council and Whitby Rural Council (Whitby Gazette 9.3.1956) to promote a coast protection scheme in the area below the Victoria Hotel, this part of the coastline has remained unprotected and prone to continuing coastal erosion.

2.5 Geomorphology

The cliffs are unprotected and subject to on-going marine erosion of the sea cliff foot. The effect of this erosion is to cause the repeated reactivation of a large multiple-rotational landslide complex, which occupies the midslopes. The landslide complex is long established and probably developed several thousand years ago. Coastal erosion would have instigated the original failure, removing the underlying bedrock and oversteepening the superficial deposits of glacial till. The till cliff would have failed along a basal shear surface, the most likely location of which is at the till/rock interface or within the top of the underlying mudrocks. Subsequent failures would have taken advantage of this shear surface leading to the formation of the current topography of the site. Superimposed onto the main landslide complex are localised failures associated with the toe, the sea cliff and the rear scarp. These failures take a number of forms including mudslides, shallow rotational slides, slumps, small rockfalls/topples and seepage/surface erosion.

Geomorphological mapping of the study area has revealed that the site can be categorised into 4 cliff units each having contrasting landslide risk and recession potential (see Figure G15.5). Moving from south to north these are as follows:

- **Unit A:** This cliff unit has the lowest relative relief (30-35m AOD) and the narrowest coastal section (30-35m). The unit is believed to contain the exposed flank of an ancient landslide system that was probably formed on the northern side slope of the King's Beck Valley during the Quaternary. Shear zones of this landslide unit evident in cores could conceivably extend under the properties fronting the Esplanade. From the surface morphology, it is likely that the ancient landslide system comprises a combination of degraded rotational failures and mudslides developed in the glacial till.

  Of particular significance is marine erosion of the sea cliff at between 0.05 to 0.15m/year. Although not severe, the direct consequence of this erosion has been the development of rotational failures in the steep till slopes beneath the Esplanade. Attempts to stabilize this area have included the construction of a sheet pile retaining wall. This measure has been marginally successful but the presence of tension cracks in adjacent section of coastal path indicate that these failures are still active.

  Marine erosion is also causing small-scale failures in the glacial till supporting the toe of the sheet pile wall. This effect is being enhanced by an interformational shear zone located in the shale sea cliff which is allowing wave energy to detach large blocks of material from the top of the Ground Wyke headland. There is much physical evidence that the sheet pile wall is on the verge of failing. Failure of this structure threatens properties fronting the Esplanade and, as a consequence, the structure has been instrumented with an electronic tiltmeter early-warning system.

- **Unit B:** Results from the tiltmeter system have indicated a consistent trend of ground movements compatible with the landslide model of the site. These movements to date have been small because of the exceptionally dry weather conditions that have persisted over the last year.

  Unit B: An area of active cliff recession promoted by marine erosion and involving a combination of mechanisms:-

  - Landsliding including debris flows, slides and small rotational failures
  - Surface erosion caused by surface run-off
  - Seepage erosion at exposed granular layers in the till
  - Reactivation of pre-existing landslides in the mid-slope bench
  - Rockfalls and topples in the sea cliff.

  These processes are strongly coupled giving rise to a repetitive sequence of cliff top failure, sea cliff retreat and mid-slope landslide reactivation. This sequence is controlled by marine erosion of the cliff foot and seepage erosion of the rear cliff which results in a natural over-steepening of the slopes.

- **Unit C:** Although broadly similar in form to Unit B, this unit contains some of the steepest cliffs and slopes of the study area. The rugged topography is directly related to the geology which changes from glacial till to the more competent sandy series of the Middle Lias. Instability in this area appears to be superficial and is confined to a combination of shallow landslides, surface erosion and seepage erosion of the rear cliff and mid-slope bench area. In this unit the dominant process appears to be marine erosion of the cliff foot at around 0.21-0.24m/year which is gradually reducing the width of the mid-slope bench.

- **Unit D:** To the north of the Mount Pleasant headland the cliffs are steeper, developed mainly in the Middle Lias Sandstones. The cliff profile is almost linear, with the mid slope bench that characteristics Units A, B and C no longer present. In this unit there appears to be very slow cliff retreat in response to wave attack at average rates of 0.15-0.18m/year.

3. IMPACT

3.1 The Problem

In the short term there was a high probability of erosion and landslide damage cutting services and utilities and the road serving the village. This would have had the effect of removing the only vehicular access into the village. This would make the village of some 340 dwellings uninhabitable.

In addition, current research on the implications of global warming and sea-level rise suggested the coastal cliff instability may have been expected to increase in the future which would have further compounded the existing problems.

3.2 Public Perception

The public perception of the problems associated with the Robin Hood's Bay area generally fell into three categories:

- Anxiety and perceiving the need for remedial works as urgent
- Acceptance of cliff instability and potential ground movement
- Failure to recognise the problems associated with cliff instability

Robin Hood's Bay is a village that depends on tourism for much of its income. A major landslide would have significantly affected the local economy. If a major landslide had occured there would have been a reduction in the number of tourists to the area, and amenities and access routes could have been damaged or restricted for a considerable length of time. In addition a number of properties could have been lost, for some of which residents cannot obtain insurance against cliff instability.

3.3 The Potential Losses

The losses associated with such an event (hence the justification for MAFF coast protection grant aid) would be considerable including:

i) Direct losses arising from landsliding and the loss of cliff top land:

- Property, services and infrastructure located in the estimated risk free market value of these assets is £5.89 million.

ii) Indirect losses arising as a consequence of the disruption following a major landslide event:

- Property, services and infrastructure located in the remainder of the old village. Such an event could isolate some 260 dwellings and businesses. The estimated risk free market value of these assets is around £17 million.
- Tourism and business losses are likely to match, if not exceed, the property losses when considered over the next 50 years or so. An estimate of £2.7 million for the annual value of these losses; discounted over 50 years this would yield a total value of around £40 million.

The assets at risk from future instability are shown in Figure G15.4.

4. ROLE OF KEY AGENCIES

Scarborough Borough Council are the Coastal Protection Authority for the area and have been engaged in the commissioning of an engineered solution to the current stability problems.

5. MONITORING AND INSTRUMENTATION

The automatic monitoring instrumentation at the site comprises 4 tiltmeters. The tiltmeters have been located at the areas where landslide risk is considered high. Studies have identified that should the sheet pile wall fail, the integrity of the stability of the site would be greatly reduced and more than likely lead to further ground failure. Therefore, it was considered necessary to site two tiltmeters one at each end of the sheet pile wall and the remaining two tiltmeters situated where they can record ground movement mid-slope and at the cliff top near the Victoria Hotel.

The tiltmeters are connected by cables to a datalogger, which continuously monitors ground movement. The datalogger is connected by a telemetric link, which enables a pager to be activated should preset ground movement threshold values within the tiltmeters be exceeded. The system can be interrogated by a modem link to a computer in the Engineer's offices or a portable computer with compatible software and modem link. The data is recorded on an hourly basis and when ground movement exceeds alarm thresholds. The tiltmeters read in two directions: normal to the coastline (the x-direction) and perpendicular to the coastline (the y-direction). There are two modes in which an alarm can be activated; by total movement and by the rate of movement per hour. The alarm thresholds set up for each tiltmeter are:

Tiltmeter 1	10mm/hr and 20mm total movement (in both x and y directions)
Tiltmeter 2	10mm/hr and 20mm total movement (in both x and y directions)
Tiltmeter 3	5mm/hr and 10mm total movement (in both x and y directions)
Tiltmeter 4	5mm/hr and 10mm total movement (in both x and y directions)

An example of the ground movements recorded by a tiltmeter in Robin Hood's Bay since January 1998 is shown in Figure G15.6. The tiltmeter results identify an overall trend of seaward movement (x direction) at tiltmeters 1 and 2 (on the sheet pile wall) of ~10 mm and ~20 mm respectively. The fluctuating readings observed in tiltmeters 1 and 2 represent the diurnal temperature variations as the sheet pile wall warms and cools during the day, which is not reflected at the same magnitude for the titlmeters located in the ground. This accounts for higher alarm thresholds for tiltmeters 1 and 2 rather than the values used for tiltmeters 3 and 4.

The system is interrogated and the data downloaded when:

- The pager is activated after ground movement alarm thresholds have been reached
- At the end of every month
- Randomly to check the operationability of the system

The pager has activated on a number of occasions when tiltmeter threshold values have been reached. Generally, the alarms have been activated due to the rapid movement in the sheet pile wall which is reflected by the high rate of changes in temperature.

6. CURRENT STATUS AND APPROACH

The purpose of the coast protection scheme is to prevent the progressive marine erosion/ landslide instability and prevent the loss of land, property and services.

The scheme was developed for Robin Hood's Bay based on the risk of a single episodic event of uncertain timing which could have resulted in considerable losses. Cliff conditions were progressively deteriorating, with the chance of failure increasing over time. This reflected:

1. Factors making the cliff more susceptible to failure, including the cumulative unloading by marine erosion, enhanced by accelerated sea-level rise and progressive failure of the cliff materials.
2. Factors increasing the frequency of potential failure triggering events, including the increased extreme sea-levels, increased storminess and increased winter rainfall.

The potential events at Robin Hood's Bay are more akin to the seawall/ embankment breach situation, where there is an annual probability, which increases with time, of a single unrepeated failure and damages.

The recent study identified the need for immediate works to be undertaken to the north and south of the existing sea defences in the vicinity of the Victoria Hotel, the cliffs between Mount Pleasant and the Esplanade and along the frontage and adjacent slopes of the Quarterdeck.

The optimum scheme, taking all factors into account, is a reinforced fill buttress supporting the failing sheet piled wall, protected by rock armour and an arrangement of piled portal frame shear keys, deep drainage and structural fill in the mid-slope bench and rear cliff. The scheme which is now being undertaken will effectively prevent further erosion, stabilize the area, protect the cliff top properties and infrastructure and enhance the amenities.

7. LESSONS LEARNT

This case study represents one of the most recent technical investigations in support of a case of government coastal protection grant aid and has been compiled taking account of best coastal and geotechnical engineering practice. The study contains all the factors likely to be of interest to the practitioner including: a description of the nature of the problem, assets at risk, approach to the investigation, monitoring and the preferred engineering solution.

Plate G15a ***Cliff top properties threatened by instability at Robin's Hood Bay***